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Thermophysical Characterization of Local Materials from a Locality in Chad for Use in Eco-Building

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Abstract

With the aim of enhancing the value of local building materials, the subject of this paper is a thermophysical study of natural Chadian clay from the eastern region of Chad, "Abeche". Samples were taken from a brickwork in Abeche from a depth of 1 m, then using a clay brick-making press, 4 × 5 × 8 cm^3 clay test tubes were made with 2%, 4%, 6% and 8% cow dung, and a 100% clay sample was used as a control. These samples underwent thermophysical characterization using the hot-wire method with a hot-plane option, yielding results that could improve thermophysical performance. The thermal conductivity of the test sample is in the order of 0.715 to 0.420 W/m. K, at 8% for cow dung, so the addition of cow dung as a percentage in the clay matrix enabled us to obtain various satisfactory thermal parameters.

Keywords

Soils, Characterization, Thermophysical, Local Building

1. Introduction

One of the challenges facing the world is energy consumption. Studies have shown that over 40% of energy consumption is in the building sector, which is also responsible for 25% of greenhouse gas emissions. In Africa, studies have shown that energy consumption is on the order of 50% - 70% [1]. Recent studies have shown that in Burkina Faso, a Sahelian country, the building sector is responsible for between 30% and 75% of electricity consumption [2]. Chad is one of the Sahelian countries lagging far behind in the energy sector and industrialized materials are important and have enabled the construction of many homes around the world, particularly cement, but its production of one ton consumes 1.7 tons of raw material and is equivalent to about 7000 Mega joules of electrical energy and fuel as was described by [3] and in addition generates approximately 0.75 and 1 ton of carbon dioxide emissions and between 1 to 2 kg of sulfur dioxide and dust [4]. In most developing countries, and Chad in particular, the income of the inhabitants does not allow them to build with industrialized materials, which are extremely expensive. It has been shown that earth is a material that meets environmental protection requirements and contributes to an appreciable energy gain to ensure thermal comfort in the home [5]. Considering the advantages of earth, notably its accessibility, recyclability and ecological quality, much work is being done to improve the performance of raw earth.

Several studies on the earth have led to determining the physical, chemical and minerologic properties. For example, in the works of [6] and [7], the authors made the geotechnical, physicochemical and minerologic characterization of the soils of certain localities of Chad with a view to their valorization in eco-construction. The results showed that the soils from these different locations are clayey in nature and suitable for construction. In other works [8]-[11], the authors sought to improve clayey soil, with adjuvants such as gum arabic, kenaf fibers (Hibiscus altissima), banana fiber or peanut shell. The results of these different works have made it possible to promote these local materials in the construction of ecological buildings. It is in this context that our work on clayey soil with cow dung additives is carried out in order to determine the thermophysical parameters that can contribute to the choice of ecological and economical construction materials with comfort in the building.

2. Materials and Methods

2.1. Study and Sampling Area Presentation

Soil samples are being taken from a locality in the Ouaddaï region, one of Chad’s 23 regions, Abeche, located in the Sahelian zone in the eastern part of the country. Situated in eastern Chad, the town of Abeche is the capital of the Ouaddaï region. It lies between latitude 13˚48'584" North and longitude 20˚50'139" East. The study area is subject to an intertropical climate with a 9-month dry season and a 3-month rainy season. The pattern of these two seasons is defined by fluctuations between dry air masses from the north (the harmattan) and humid maritime air masses from the southwest (the monsoon). The average annual rainfall is around 300 mm. The region’s temperature varies according to the season. The average annual temperature in Abeche is around 28˚C, varying between 16˚C and 35˚C in the cold season (December to February) and between 25˚C and 41˚C in the dry season (April and May). The soil sampling site, in the province of Abeche, is marked by a blue triangle on the map.

Figure 1 and Figure 2 show, respectively, the mapping of the locality and the sampling site for the samples studied.

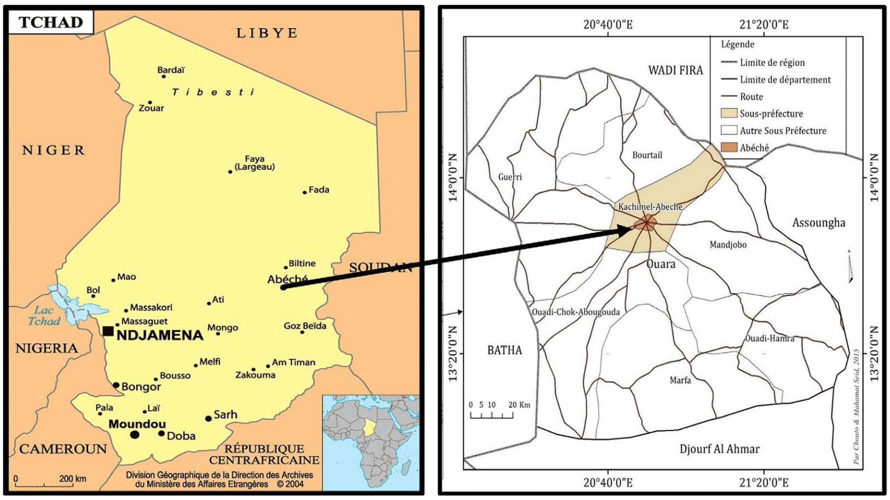

Figure 1. Mapping of the study region.

Figure 2. Sampling site.

Figure 2 shows the photograph of the soil sampling site to be studied.

2.2. Study Materials

a) Soil

The soil taken from the site was identified by geotechnical and physico-chemical methods in the article [12]. It resorts that these floors are clay and adapts for the manufacture of compressed earth bricks.

b) Dug cow

These are mainly local materials derived from animal biomass (cow's dung in Figure 3), which are used to mix with the study material, clay. The choice of these local materials is justified by their abundance in Chad [13]. In the work [14], the authors showed through energy dispersive spectrometry (EDS) analysis that cow dung mainly contained silica, alumina, calcium, potassium, magnesium, phosphorus, iron and sulfur. In addition, the authors mixed cow dung with soil and used it as coatings. In the work [15], another study highlighted the effect of cow dung on microstructural changes of bricks (adobes). The authors showed that cow dung reacts with clay minerals such as kaolinite and quartz to produce an insoluble amino silicate, which sticks to isolated soil particles. Moreover, it has also been observed that the presence of fiber in cow dung prevents the propagation of cracks and strengthens the brick (increasing its resistance).

Figure 3. Cow dung.

2.3. Formulation of Samples

In **Table 1**, we propose the formulation of the samples for the manufacture of the 4 × 5 × 8 cm^3 test tubes.

Table 1. Formulation of samples.

Samples	Percentages of clays and cow dung				
Cow dung	0%	2%	4%	6%	8%
Abeche clay	100%	98	96	94	92

2.4. Preparation of Samples

At first, a mass of the sample is taken, sifted (2 mm), then pledged with the digital scale and mixes with the cow dung (0%, 2%, 4%, 6% and 8%) and water. This mixture (clay + cow's dung + water) is kneaded and preserved for 20 minutes to have a perfectly homogeneous mixture. **Figure 4** shows the different stages of the preparation of the samples.

2.5. Manufacture of Samples

The production of soil samples is ensured by a device (**Figure 5**) set up on site allowing reproducible samples to be obtained.

- ✓ First the mixture (clay + cow dung + water) of a mass (450 ± 1 g) is introduced into the mold;

- ✓ Second the mold is closed by a plate and tightened by a bolt;
- ✓ Third a pressure around 4.3 MPa is applied via a hydraulic jack;
- ✓ Fourth the bolt is loosened to release the samples 4 × 5 × 8 cm^3 then they are spread on the mulches for drying at the laboratory temperature about 32˚C.

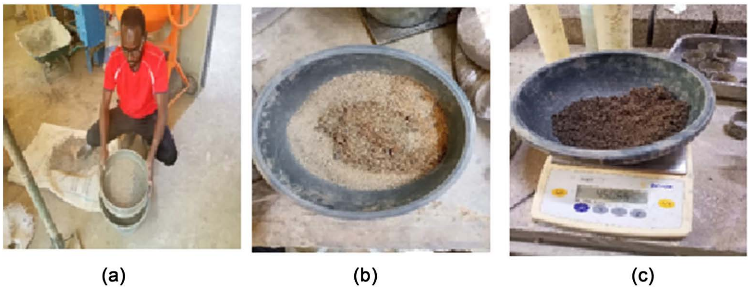
(a) (b) (c)

Figure 4. (a) Dry samples, (b) (Clay +cow's dung), (c) Humidified samples.

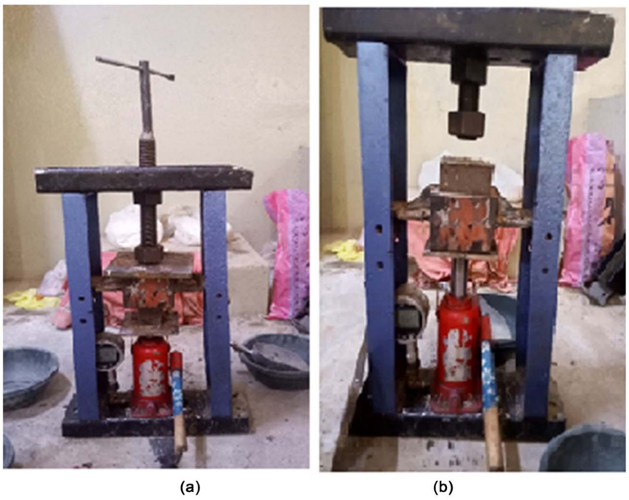
(a) (b)

Figure 5. Disposition of manufacturing.

Figure 6. Samples 4 × 5 × 8 cm^3.

Figure 6 presents the manufacturing steps for 4 × 5 × 8 cm^3 test pieces to allow thermophysical characterization.

2.6. Thermophysical Characterization

The determination of the thermophysical properties of these bricks are parameters which could be of great use for the evaluation of their effectiveness in the thermal insulation of buildings.

The thermophysical properties of these earth specimens to be studied in this paper are:

- ✓ Thermal conductivity;
- ✓ Thermal effusivity;
- ✓ Thermal diffusivity;
- ✓ And specific heat.

The device, shown in **Figure 7**, consists of a thermal shock probe which will be placed between two identical samples of the material to be characterized, and an electronic. The probe principle and device were developed by CSTB. They are also based on ASTM D5930-97 and RILEM recommendation AAC 11-3 [16].

The procedure consists of generating a low local temperature rise in the material (then considered to be in thermal equilibrium) and measuring the temperature rise over a very short time. The following equation relates thermal conductivity to temperature variation with respect to time.

$$\Delta T = \frac{q}{(4\pi\lambda)} * \left(\ln(t) + cste\right) \tag{1}$$

With λ the thermal conductivity in $\text{W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$, q the linear flow injected in W/m, ΔT the temperature difference in K and t the duration of the test in *s*.


(a) (b)

Figure 7. Device hot wire (a)-acquisiton box and labtop, (b)-hot wire probe.

- ✓ Effusivity represents both the capacity of the material to store energy per unit of volume between two thermal states differing by one Kelvin (Cvol) but also its capacity to facilitate the transmission of heat throughout its entirety. volume (λ) [17]

$$\Delta T = q\left(RT - \frac{Cs}{Eff\,2} + 2\frac{\sqrt{t}}{\left(Eff\sqrt{\pi}\right)} \right) \tag{2}$$

With Eff, the effusivity in $\text{J}\cdot\text{m}^{-2}\cdot\text{K}^{-1}\cdot\text{S}^{-1}$, T the temperature in degrees *K*, q the injected flux density in W/m^2, t the duration in *s*, Rt the total resistance, *i.e.* the contact resistance in K·m²/W and *Cs* an intrinsic characteristic of the probe in J/kg·m²·K.

The other thermophysical parameters are obtained by deduction through the different formulas which allow them to be linked.

- ✓ Diffusivity determines the speed of heat transmission and is obtained by

$$D = \frac{\lambda}{\rho * C\rho} \text{ with CP, the specific heat} \tag{3}$$

- ✓ Specific heat is measured by weight by the volume of one m³ of a given material (density). She obtained by deduction, from the formula:

$$CP = \frac{E^2}{(\rho * \lambda)} \tag{4}$$

3. Results and Discussions

The thermophysical results of the 5 × 4 × 8 cm samples of clay plus (cow dung), are grouped in **Table 2** below.

Table 2. Values of thermophysical parameters of Abeche clay.

Thermophysical parameter	Percentage of cow dung with Abeche clay				
	0%	2%	4%	6%	8%
M (kg)	250	240	231	219	207
λ (w/m·K)	0.715	0.680	0.520	0.501	0.420
Rth (m²·˚C/w)	0.280	0.294	0.385	0.399	0.476
CP (KJ/m³K)	904	659	512	474	356
ρ (kg/m³)	1563	1500	1444	1369	1294
E (J/kg·K)	1005	820	620	570	440
D (m²/s)	5.06E−07	6.88E−07	7.03E−07	7.73E−07	9.11E−07

3.1. Thermal Conductivity

Figure 8 shows the variation in conduction as a function of the as a function of the percentage of cow dung used in the manufacture of the earth samples (5 × 4 × 8 cm).

From the result of **Figure 8**, it can be observed that the thermal conductivity varies inversely with the increase in the percentage of cow dung. We notice a decrease in conductivity as the percentage of cow dung increases. In fact, cow dung contains part of the fiber and the presence of the fiber increases the void volumes in the test tubes, which reduces the thermal conductivity of clay matrices with more cow dung than that of 100% clay. For a sample without adding cow dung, the conductivity is around 0.715, rising to 0.420 W/m. K for a 2% sample of cow dung. This result is not very far compared to those in the literature in the work of [18], we note that the sample with 100% clay, the conductivity is

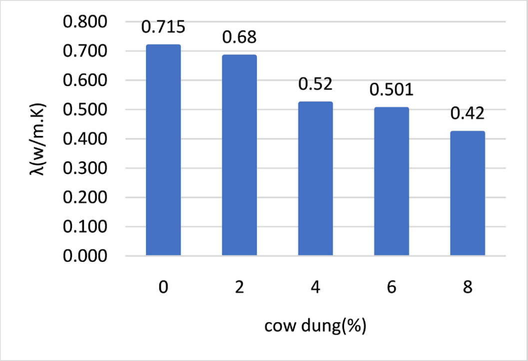

Figure 8. Thermal conductivity depending on the percentage of cow dung.

of the order of 0.8 W/m·K and comparing that of 5% of dung and 95% of clay, the conductivity is of the order of 0.3W/m·K, on the other hand, can be explained by the porous structure of fiber itself increases the porosity of the composite which reduces and the absorption power of fiber will increase the humidity rate important to the fiber, which promotes the decrease in thermal conductivity. In the works of [19], the authors found that the water absorption of date palm fibers increases with the fiber content. And also, in the works [20], the water content of cocoa fibers increases with the quantity of these fibers.

By comparing the conductivity values found with other existing results in the literature, we obtain correct values.

3.2. Thermal Resistance

Variation in thermal resistance as a function of cow dung percentage

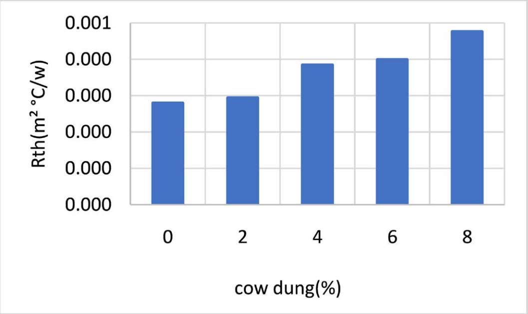

Figure 9. Thermal resistance as a function of the percentage of cow dung.

There is a constant increase in thermal resistance with the increase in percentage of cow dung in **Figure 9**. Because thermal resistance is inversely proportional to thermal conductivity. Indeed, Rth = e/λ with thickness $e = 20$ cm in this case. This increase, depending on the percentage addition of cow dung, can be explained by the simple fact that the quantity of cow dung in the mixture contains fiber which tends to increase the ports and therefore the thermal conductivity is slowed down.

3.3. Density

Variation in density of the samples specimens (soils) as a function of the percentage of cow dung is given in **Figure 10** bellow.

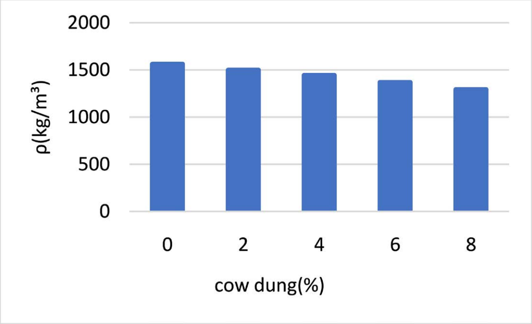

Figure 10. Density as a function of the percentage of cow dung.

Figure 10 shows a decrease in density depending on the incorporation rates of 2%, 3%, 4%, 6% and 8% respectively of cow dung, compared to the 100% clay matrix. This can be explained by the fact that cow dung takes time to lighten the material. In the work of [19], the author showed that the addition of 0.5% of rice straw lowers the dry apparent density from 1929 kg/m^3 to 1916 kg/m^3. Comparing our results with the other cited results, we obtain an acceptable variation in density.

3.4. Thermal Effusivity

Figure 11 shows the decreasing variation in thermal effusivity as a function of the cow dung incorporation rate.

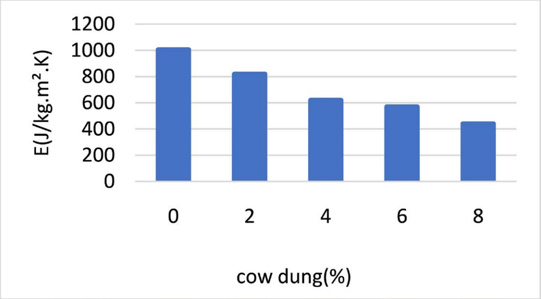

Figure 11. Effusivity as a function of the cow dung incorporation rate.

Comparing the values of thermal effusivity obtained with that found by [18] varies from (1150 to 550 W/m^2/K) for percentages of (0% to 5%). Our obtained values are acceptable.

3.5. Specific Heat

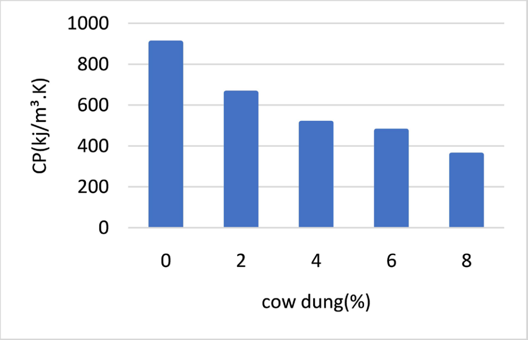

Figure 12. Specific heat as a function of the percentage of cow dung.

According to the results in **Figure 12** shows that the specific heat varies inversely with the increase of cow dung, which is very remarkable compared to the matrix without adding cow dung. The values obtained by [18] vary from (900 to 650 J/kg/K) for percentage of (0% to 5%) of cow dung. These values are in the same magnitude as our obtained values.

3.6. Thermal Diffusivity

Figure 13 also shows a remarkable reduction in the addition of cow dung compared to the samples, *i.e.* 100% clay without the addition of cow dung.

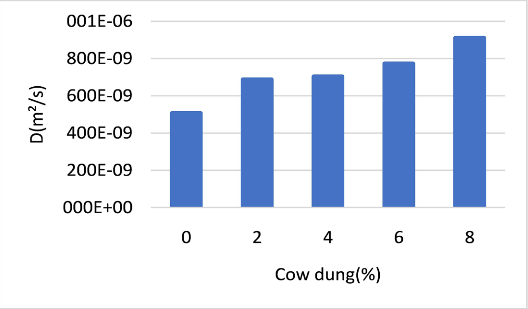

Figure 13. Diffusivity as a function of the percentage of cow dung.

4. Conclusion

The experimental study of thermophysical properties provides indications for the choice of material with a view to minimizing thermal inputs in buildings. We note a decrease in the values of thermal conductivity and diffusion depth with the addition of cow dung. All samples studied have thermal conductivities lower than 0.715 $W \cdot m^{-1} \cdot K^{-1}$. Considering the thermophysical properties, the specimens of earth mixed with clay present the best advantages, low thermal conductivities (0.41 $W \cdot m^{-1} \cdot K^{-1}$) and low densities. In our study, we produced new materials incorporating cow dung with a view to improving their thermal insulation performance in buildings. On an ecological level, the use of these materials contributes to reducing the emission of carbon dioxide and to valorizing cow dung as Chad is known for its significant quantity in cattle.

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Conflicts of Interest

We declare that there is no conflict of interest and that this article could be published.

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